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GB 0276374 A
EP 0514702 A1
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(54) Abstract Title
Active rail health monitoring system

(57) There is provided both apparatus and method for testing or monitoring the integrity of a rail. The testing is performed by applying a known vibration sequence to the rail by use of an actuator; and detecting a corresponding vibration sequence received by a sensor associated with the rail at a location distant from the actuator.

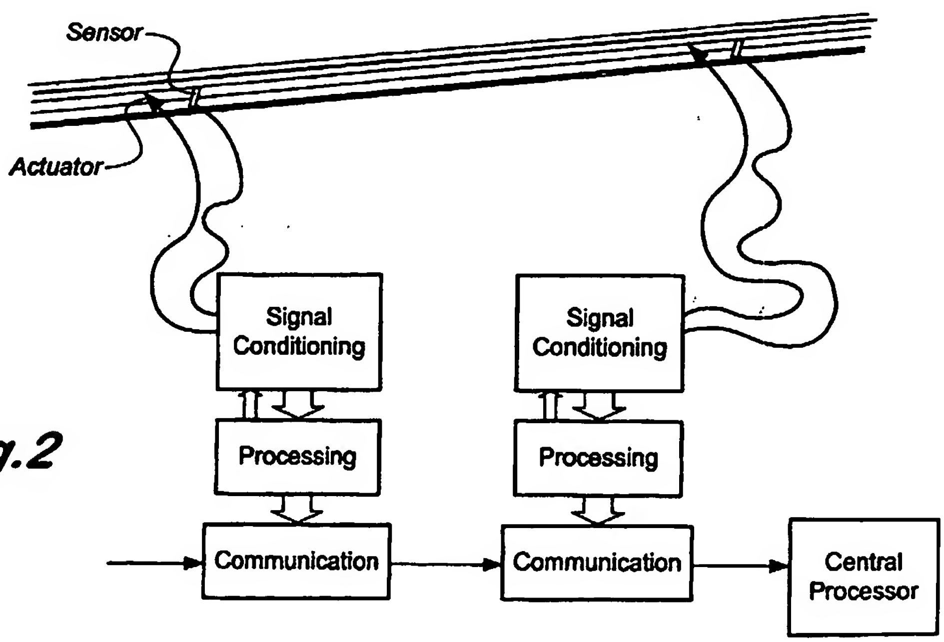

Fig.2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

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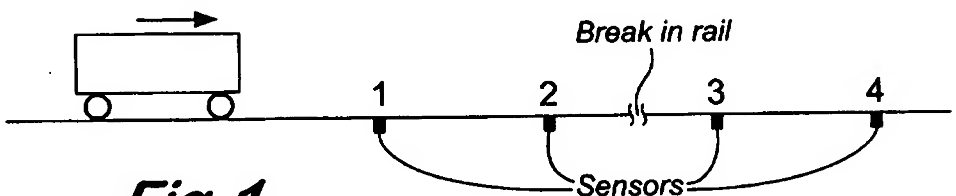
Break in rail
1
2
3
4
Sensors

Fig. 1

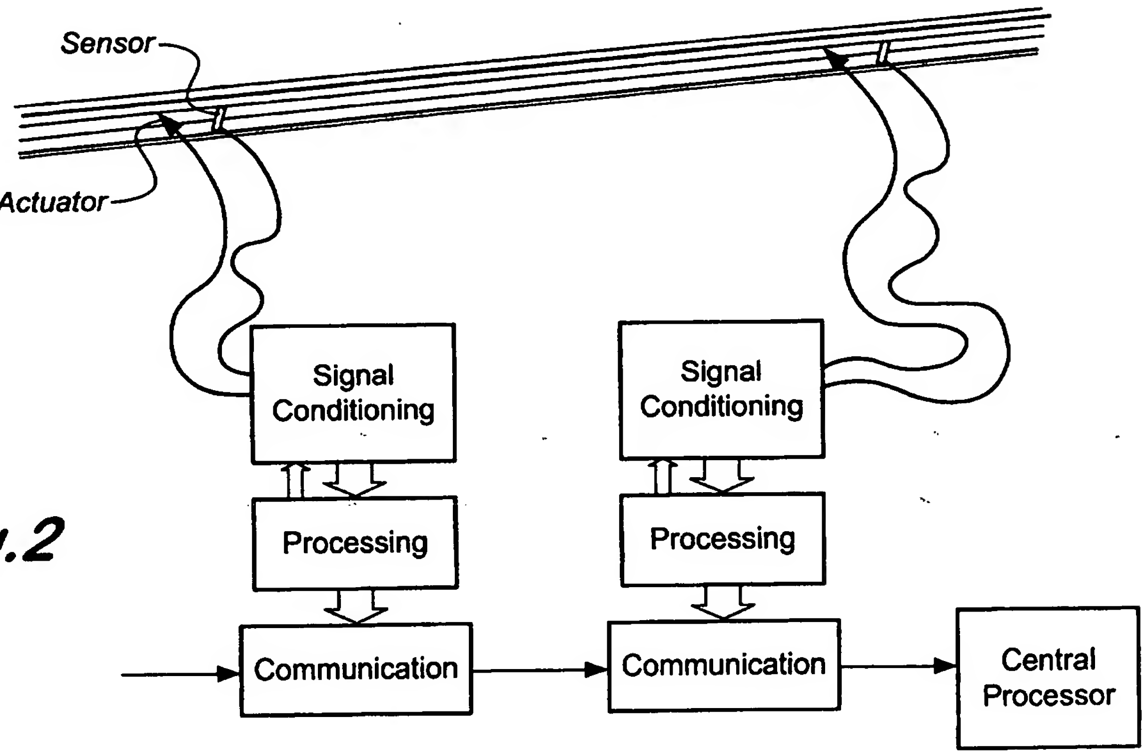
Sensor
Actuator
Signal Conditioning
Processing
Communication
Signal Conditioning
Processing
Communication
Central Processor

Fig. 2

AN ACTIVE RAIL HEALTH MONITORING SYSTEM

The present invention relates to methods and apparatus for monitoring the condition of rails, such as in a railway network..

The problem of broken rails on the world's rail networks is of increasing concern. There is an increased likelihood of such breaks and increased risks associated with such breaks for a number of reasons.

These reasons include the great age of much of the track; increasing axle loads and speeds; increased rail traffic; and limitations of current inspection technologies.

This invention aims to provide early warning of breaks and faults in rails, and hence prevent serious accidents.

The method used at the moment to prevent accidents resulting from rail faults is regular inspection of rails using ultrasonic equipment. The technique of ultrasonic inspection involves looking for small, subsurface defects (cracks) in the railhead that could seed a transverse crack and subsequent rail failure. There are many different types of

defect and not all are reliably detectable even using state of the art ultrasonic equipment. Of particular concern are 'rolling contact fatigue' faults, which may be on the increase due to increased axle loads and speeds. The two most commonly cited examples of these fatigue defects are 'squats' and 'gauge corner cracks' [2]. Squats occur on the top of the railhead and start as horizontal cracks a few millimetres below the surface. These cracks can then branch downwards into the rail and hence a transverse crack is formed resulting in rail failure. A gauge corner crack starts because of a phenomenon called 'shelling' on the gauge corner (inside top corner of the rail). Small 'shells' of steel come away from this corner because of forces applied by the wheel and the subsequent wear of the rail. Transverse cracks propagate from the resulting surface defects.

It is difficult to detect a transverse crack propagating from a 'squat' because the transverse crack is hidden below the horizontal cracks from which it branches. The shelling that causes gauge corner cracking is also difficult to detect because it is on the side of the railhead, although state-of-the-art ultrasonic detectors employ side-firing transducers to overcome this problem.

The increasing number of fatigue defects, and the increasing burden on the inspection and maintenance process conflicts with the demands of the rail operators to keep trains running. The rail structural health monitoring system proposed here aims to alleviate this conflict of interests. It is proposed that the system be used to monitor the condition of a section of track that has a known sub-critical defect or a number of defects, so that safety is not compromised while it is waiting to be repaired. It may also be that sections of track that may have a higher risk of failure (sections carrying high tonnages, bends used by high speed trains, or older sections of track), could have permanently installed systems.

Two examples of known systems will now be discussed. One is described in US patent 5743495, April 28 1998, attributed to Welles et al and assigned to GEC [3]. In this patent, a passive vibration monitoring system is proposed. Vibration sensors are placed at regular intervals along the track. Each of these is linked to a central processor. The system relies on a sudden drop in the vibration amplitude as a train passes a sensor close to a break in the rail. Figure 1 schematically illustrates a system as described in US Patent 5743495.

The vibration level generated by the moving train at, for example, Sensor 1 in Figure 1 increases as the train approaches, reaches a peak as the train passes over the sensor, begins to decrease as the train passes the sensor, and will suddenly disappear altogether once the train has completely passed the break in the track. A similar pattern applies to the vibration signal at Sensor 2. For sensors beyond the break, the vibration will suddenly appear rather than disappear. The system proposed in this patent is only designed to detect breaks in the track as it relies purely on the inability of a broken rail to transmit vibration. The system is also reliant on passing trains to detect faults.

The second known system is described by Rose, J. L., in *'Elastic Wave Analysis for Broken Rail Detection'*, Proceedings of the 15th World Conference on Non-destructive Testing, Rome, October 2000 [4]. This system is also passive and relies on the train to generate the waves in the rail. A similar concept is described in Reference [3], except that the description implies that it is known *a priori* that a train is approaching a sensor. If one sensor detects the vibration from the train and the next does not, there is a break between the two sensors. The paper also discusses the different modes for wave propagation. It is rather vague, but implies that certain modes are more likely to be affected by partial

breaks in the rail. Each propagating mode only propagates above its 'cut-off' frequency and it is implied in Reference [4] that selection of a particular frequency range may allow the detection of partial breaks in the rail.

The concept of continually monitoring the condition of a structure falls under the umbrella of structural health monitoring. A new technique proposed for structural health monitoring is spread spectrum ultrasonics (Reference [5]). In this technique, ultrasonic transducers fill a structure with a broad band encoding sequence. The cross correlation between the sequence radiated into the structure and that received by ultrasonic receivers constitute an acoustic 'signature' of the structure. Any structural changes will be somehow reflected in the acoustic signature. This method of non-destructive evaluation has certain similarities to the rail health monitoring approach suggested here. The spread spectrum approach to non-destructive evaluation is covered by US Patent 5461921.

The present invention therefore aims to alleviate one or more of the difficulties associated with the known system described above.

Accordingly, the present invention provides a method for testing or monitoring the integrity of a rail by applying a known vibration sequence to the rail by use of an actuator; and detecting a corresponding vibration sequence received by a sensor associated with the rail at a location distant from the actuator.

The step of applying a known vibration sequence may comprise the step of applying a known pseudorandom vibration sequence.

The step of applying a known pseudorandom vibration sequence may comprise the steps of: providing a known pseudorandom digital sequence; filtering a signal representing the pseudorandom digital sequence; and applying the filtered signal to the actuator.

The step of applying a known vibration sequence may comprise the step of applying a number of continuous discrete frequency vibrations to the rail.

The step of applying a known vibration sequence may comprise the steps of applying a random vibration sequence; and communicating information representing the random vibration sequence to control

circuitry associated with the sensor. In this case, the step of applying a known vibration sequence may comprise the steps of generating a random digital sequence; filtering a signal representing the random digital sequence; and applying the filtered signal to the actuator.

The method of the present invention may further comprise the steps of detecting vibrations caused by an approaching train, and substantially eliminating such vibrations from the received vibration sequence.

The method of the present invention may further comprise the steps of calculating suitable parameters for rail fault detection, based on the known vibration and the corresponding detected vibration.

The present invention also provides apparatus for testing or monitoring the integrity of a rail. Such apparatus comprises an actuator for attachment to the rail; a signal conditioning and processing unit for supplying a known vibration sequence signal to the actuator; a sensor for attachment to the rail; and a signal conditioning and processing unit for receiving corresponding vibrations from the rail in response to actuation by the actuator.

The apparatus may further comprise communications circuitry linked to the respective signal conditioning and processing units, thereby to enable communication between the respective signal conditioning and processing units.

The apparatus may further comprise a central processor in communication with the respective signal conditioning and processing units. Such central processor may be operable to receive and indicate rail integrity data based on the received vibrations.

The signal conditioning and processing unit associated with the actuator may be adapted to transmit, and the signal conditioning and processing unit associated with the sensor is adapted to receive, information relating to the vibration sequence applied by the actuator to the rail.

The signal condition and monitoring unit associated with the sensor may comprise a memory arranged to store information representing the known vibration sequence applied to the actuator.

The sensor may be located distant from the actuator.

In an embodiment of the apparatus according to the invention, a sensor and an actuator may be substantially collocated at each of a plurality of points along a length of the rail. At each point, the respective sensor and the respective actuator may share a common signal conditioning and processing unit.

In an embodiment of the apparatus according to the invention, an actuator is located at a first point on the rail; a first sensor is located at a second point on the rail, distant along the rail in a first direction from the first point; and a second sensor is located at a third point on the rail, distant along the rail in a second direction from the first point. The first and second sensors are then each arranged to receive the vibration sequence from the actuator.

In an embodiment of the apparatus according to the invention, a sensor is located at a first point on the rail; a first actuator is located at a second point on the rail, distant along the rail in a first direction from the first point; and a second actuator is located at a third point on the rail, distant along the rail in a second direction from the first point. The first and second actuators are then each arranged to supply a respective vibration sequence for detection by the sensor.

In any method or apparatus according to the present invention, an array of actuators and sensors may be distributed at intervals along the rail. In such embodiments, any one of the sensors can be associated with any one or more of the actuators of the array.

In any method or apparatus according to the invention, testing or monitoring the integrity of the rail may comprises detecting the presence or absence of at least one of : cracks in the rail; breaks in the rail; severe changes in track geometry; buckling; and items lying on the rail.

The above, and further, objects advantages and characteristics of the present invention will become more apparent with reference to the following description of certain embodiments of the invention, given by way of examples only, with reference to the accompanying drawings, in which:

Fig. 1 schematically shows a known system for detecting faults in rails, by detecting vibrations generated by passing trains; and

Fig. 2 schematically shows apparatus for monitoring the integrity of a rail according to an embodiment of the present invention.

The present invention provides a system for the detection of serious faults (breaks or large open cracks) in rails of a railway track, or items lying on the rail, or other faults relating to the rail. In an embodiment of the invention, the system consists of a series of vibration measurement/excitation sub-systems placed at intervals along the track. At each position the rail is excited by a known signal (which may be either deterministic or pseudo-random). Corresponding vibrations are received by one or more sensors. A cross correlation, cross spectrum or transfer function between adjacent measurement/excitation sub-system positions may be calculated.

Any significant change in the measured quantities for each length of track may indicate a fault of some sort, which could be reported to a central processing point. A more detailed analysis of the measured quantities may yield some information about the nature of the fault or the exact location of the fault. The use of multiple actuators or sensors at each measurement/excitation position, would allow the excitation of

specific propagating modes in the rail, which, in turn, may allow further diagnosis of the fault.

The proposed system relies on the attachment of vibration sensors and actuators to the rail. Sensors and actuators may be attached to the rail at regular intervals. The rail is a natural wave-guide. The characteristics of the path between adjacent sensor/actuator positions can be measured at regular time intervals. Significant changes in the characteristics indicate a potential problem with that section of track.

It is well known that vibration generated by a train can travel for several miles along the rails it is running on [4] and it is clear from reference [4] that breaks or significant faults in rails will affect the propagation of waves in the rail. Thompson has extensively studied wave propagation in rails below 5000Hz [6]. At any frequency significantly below 20kHz, flexural waves and longitudinal waves propagating along the length of the rail will dominate. Shear waves and longitudinal waves propagating internally in any other direction will only become important significantly above 20kHz (and the distance over which these travel will be much smaller).

As for any waveguide, wave propagation consists of a number of propagating modes. There is a longitudinal wave propagating along the length of the rail. Then there are a number of transverse modes where the particle motion is transverse to the propagation direction and which may involve distortion of the rail cross section. These propagating modes are the subject of a study by Thompson [6]. The mode shape for propagating modes is a function of frequency, and the propagating mode is characterised by the variation of wavenumber with frequency. Flexural waves are dispersive and hence have a non-linear relationship between wavenumber and frequency. Each propagating mode only propagates above its cut-off frequency.

It is reasonable to postulate that any flexural wave motion that is dominated by shear deformation (for rails, shear deformation becomes increasingly important above 500Hz) will not be supported by a complete transverse break in the rail. Audio frequency flexural waves will be largely unaffected by small-scale internal faults. An open transverse crack that covers a significant fraction of the rail cross section, however, is likely to have an effect on propagating flexural waves.

The proposed rail health monitoring system is an active system, that is, the rail is excited by a known signal. Known (passive) vibration-based approaches to broken rail detection simply measure the vibration induced by approaching trains. The advantages of an active system include being able to: accurately characterise the structural dynamics of the rail between measurement points; carry out measurements when no trains are present; excite specific propagating modes; apply matched filtering to the signals and thereby improve resistance to clutter and noise; and continuously monitor rail condition and perhaps predict the point of failure, or when replacement or repair should occur.

Figure 2 illustrates the basic elements envisaged for an example system according to the present invention. For each measurement position, both a sensor and an actuator are provided. The actuator could be a straightforward electro-dynamic device or, alternatively, either piezo-ceramic or magnetostrictive. There would also be a sensor or sensors (most likely accelerometers) approximately collocated with the actuator. The sensors may be placed at distances of up to 1km apart.

The system being proposed could be used to detect faults other than cracks. Severe changes in track geometry (e.g. buckling) and items

lying on the rails would both in some way affect flexural wave propagation. In addition, a train passing over would almost certainly swamp the excitation signal, so the system will need to differentiate vibration due to passing trains and to ignore measurements at these times.

Using the hardware arrangement specified above, a number of possible monitoring strategies could be employed, each representing a different embodiment of the invention.

One possible strategy uses a known pseudo-random sequence. In this approach, each position would have a unique random sequence associated with it. The actuator would be periodically fed with the sequence and adjacent sensor positions could calculate the cross-correlation or cross spectrum between that sequence and the vibration detected at their sensors. Hence, the cross correlation or cross spectrum between adjacent positions may regularly be updated. Any large change in the cross correlation or cross spectrum between two positions may indicate a problem. Detailed analysis of the cross correlation or cross spectra may give a more accurate position for the fault and some

indication as to its nature. The pseudo-random sequence would simply be band limited to an appropriate frequency range.

Another possible strategy uses continuous random excitation. This method involves continuously exciting with a random sequence from each position and simultaneously transmitting that sequence to adjacent positions using a communications link. If the auto-spectrum were also measured at each position, the transfer function between all adjacent positions could be continuously measured.

Another possible strategy uses discrete frequency signals. It is conceivable that broadband measurements would not be required to detect changes associated with faults in the rail. A unique group of discrete frequencies could be assigned to each position. The amplitude and phase changes for those frequencies could be measured at adjacent positions.

The advantage of both the single frequency or pseudo-random sequence approaches is that the excitation signal does not need to be transmitted between positions, greatly reducing bandwidth required for the communication system.

A further embodiment of the invention would use multiple actuators and/or sensors at a single position. Multiple actuators in a single transverse plane would allow selective excitation of particular propagating modes. Similarly, the use of multiple sensors would allow specific propagation modes to be measured. If some modes were found to be associated with a particular type of fault, then multiple actuators and/or multiple sensors would allow some diagnosis to be done. In addition, it may be that various innocuous changes to the track tend to affect some modes and not others. Targeting only those propagating modes sensitive to faults could eliminate these innocuous effects. Use of two sensors at relatively closely spaced positions along the track would allow the vibration to be decomposed into forward and backward going components. Assuming that the excitation signals at all positions are mutually uncorrelated, this makes it possible to look for reflections from discontinuities.

Two related signal processing issues need to be addressed in measuring the response between measurement positions on the rail. The first problem is noise. It must be assumed that the environment could be extremely noisy. For the broadband approaches the signal to noise ratio

can be increased by either, increasing the excitation power, increasing the length of the random sequence, or, in the case of continuous random excitation increasing the period over which averaging occurs. Clearly there is a practical limit on the extent to which excitation power can be increased, which will depend on actuator type, size and cost restrictions. The length of the random sequence or time taken for averaging will have an impact on the amount of processing required to calculate cross-correlations. In addition, the length of the sequence used will dictate how often the rail characteristics can be measured.

Much of the extraneous vibration will be at low frequencies and it is therefore proposed that, for the broadband implementation, the sensor outputs be highpass filtered to eliminate as much of the extraneous energy as possible. Similarly, the random sequence used for excitation would be high pass filtered as well as lowpass filtered for smoothing purposes.

Improving the signal to noise ratio for deterministic excitation signals could be achieved by utilising a number of the established methods for finding deterministic signals in noise.

A problem may be presented by simultaneous measurement and excitation at a measurement station. Clearly, the excitation at a measurement station will dominate the signal from the sensor at that position and may swamp the signal from other excitation positions. One approach is simply to alternate measurement and excitation phases. Another would be to use the known excitation signal as a reference signal in an adaptive noise canceller and remove the excitation signal from the signal returned by the sensor.

REFERENCES

The following documents are referred to in the above description. Each of these documents, and other documents referred to in the description, are incorporated herein in their respective entirety.

1. Sawley, K., Reiff, R., Rail Failure Assessment for the Office of the Rail Regulator. Transportation Technology Center, Inc. October 25, 2000

2. Clayton, P., Surface Damage Phenomena in Rails, Proc. Contact Mechanics and wear of Rail/Wheel systems, 1982

3. Welles II, K. B., Ali, I., System for detecting broken rails and flat wheels in the presence of trains, US Patent No. 5743495, April 28 1998.

4. Rose, J. L., Elastic Wave Analysis for Broken Rail Detection, Proceedings of the 15th World Conference on Non-destructive Testing, Roma, October 2000

5. Russell, S. F., K. Hoech, Kayani, J. K., Afzal, Mukammad A. K., and Wormley, S. J., Spread-Spectrum Ultrasonic Evaluation - Final Report, Iowa State University, June 30, 1994.

6. Thompson, D.J., Experimental analysis of wave propagation in railway tracks, Journal of Sound and Vibration, 203(5), 867-888, 1997.

CLAIMS:

1. A method for testing or monitoring the integrity of a rail by:

- applying a known vibration sequence to the rail by use of an actuator; and

- detecting a corresponding vibration sequence received by a sensor associated with the rail at a location distant from the actuator.

2. A method according to claim 1 wherein the step of applying a known vibration sequence comprises the step of applying a known pseudorandom vibration sequence.

3. A method according to claim 2 wherein the step of applying a known pseudorandom vibration sequence comprises the steps of:

- providing a known pseudorandom digital sequence;

- filtering a signal representing the pseudorandom digital sequence; and

- applying the filtered signal to the actuator.

4. A method according to claim 1 wherein the step of applying a known vibration sequence comprises the step of applying a number of continuous discrete frequency vibrations to the rail.

5. A method according to claim 1 wherein the step of applying a known vibration sequence comprises the steps of:

- applying a random vibration sequence; and
- communicating information representing the random vibration sequence to control circuitry associated with the sensor.

6. A method according to claim 5 wherein the step of applying a known vibration sequence comprises the steps of:

- generating a random digital sequence;
- filtering a signal representing the random digital sequence; and
- applying the filtered signal to the actuator.

7. A method according to any preceding claim, further comprising the step of detecting vibrations caused by an approaching train, and substantially eliminating such vibrations from the received vibration sequence.

8. A method according to any preceding claim further comprising the steps of calculating suitable parameters for rail fault detection, based on the known vibration and the corresponding detected vibration.

9. Apparatus for testing or monitoring the integrity of a rail, comprising:

- an actuator for attachment to the rail;
- a signal conditioning and processing unit for supplying a known vibration sequence signal to the actuator;
- a sensor for attachment to the rail; and
- a signal conditioning and processing unit for receiving corresponding vibrations from the rail in response to actuation by the actuator.

10. Apparatus according to claim 10 further comprising communications circuitry linked to the respective signal conditioning and processing units, thereby to enable communication between the respective signal conditioning and processing units.

11. Apparatus according to claim 10, further comprising a central processor in communication with the respective signal conditioning and processing units.

12. Apparatus according to claim 11 wherein the central processor is operable to receive and indicate rail integrity data based on the received vibrations.

13. Apparatus according to any of claims 10-12, wherein the signal conditioning and processing unit associated with the actuator is adapted to transmit, and the signal conditioning and processing unit associated with the sensor is adapted to receive, information relating to the vibration sequence applied by the actuator to the rail.

14. Apparatus according to any of claims 9-13 wherein the signal condition and monitoring unit associated with the sensor comprises a memory arranged to store information representing the known vibration sequence applied to the actuator.

15. Apparatus according to any of claims 9-14 wherein the sensor is located distant from the actuator.

16. Apparatus according to any of claims 9-15 wherein a sensor and an actuator are substantially collocated at each of a plurality of points along a length of the rail.

17. Apparatus according to claim 16 wherein, at each point, the respective sensor and the respective actuator share a common signal conditioning and processing unit.

18. Apparatus according to any of claims 9-17, comprising:

- an actuator at a first point on the rail;
- a first sensor located at a second point on the rail, distant along the rail in a first direction from the first point; and
- a second sensor located at a third point on the rail, distant along the rail in a second direction from the first point,

wherein first and second sensors are each arranged to receive the vibration sequence from the actuator.

19. Apparatus according to any of claims 9-18, comprising:

- a sensor at a first point on the rail;

- a first actuator located at a second point on the rail, distant along the rail in a first direction from the first point; and

- a second actuator located at a third point on the rail, distant along the rail in a second direction from the first point,

wherein first and second actuators are each arranged to supply a respective vibration sequence for detection by the sensor.

20. A method or apparatus according to any preceding claim, comprising an array of actuators and sensors distributed at intervals along the rail.

21. A method or apparatus according to claim 20, in which any one of the sensors can be associated with any one or more of the actuators of the array.

22. A method or apparatus according to any of claims 9-19 wherein testing or monitoring the integrity of the rail comprises detecting the presence or absence of at least one of :

- cracks in the rail;
- breaks in the rail;
- severe changes in track geometry;

- buckling; and
- items lying on the rail.

23. A method substantially as described and/or as illustrated in Fig. 2 of the accompanying drawings.

24. Apparatus substantially as described and/or as illustrated in Fig. 2 of the accompanying drawings.

CHARTER MARK

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INVESTOR IN PEOPLE

Application No: GB 0106133.2 28
Claims searched: 1 to 22

Examiner: Peter Easterfield
Date of search: 18 April 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:
UK Cl (Ed.S): G1G (GPCX)
Int Cl (Ed.7): B61L 23/04; B61K 9/10
Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X, Y	GB 0276374 A	(SCHIEFERSTEIN) whole document	1,9
X, Y	EP 0861764 A1	(NIPPON SIGNAL) see figs 32 - 46	1,9
X, Y	EP 0514702 A1	(TELEFUNKEN) whole document	1,9
Y	US 5386727 A	(SEARLE) whole document	1,9
Y	WO 94/20847 A1	(HERZOG) whole document	1,9

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